The Role of Geologic Mapping in Hydrologic Investigations

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Bedrock Regional Aquifer Systematics Study (BRASS) Project

USGS Geologic Division

Fractured Rock Aquifer Meeting

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Premise:

A new generation of geologic maps provide previously unavailable insight into the framework of fractured rock aquifers.

Hasn't it already been mapped?

Historical Perspective of Geologic Mapping

Pre – 1960s

- Prior to Plate Tectonics
- Stratigraphic approach
- 1:62,500 or smaller
- Mineral resources
- Paper maps
- Limited fracture data

1960s – 1990s

- Plate Tectonics bandwagon
- Structural complexity added
- 1:62,500 to 1:24,000
- Tectonics research
- Paper maps
- Limited fracture data

1990s – present

- Plate Tectonics
- Structural complexity added
- 1:24,000 or larger
- Tectonics, Hazards, & Water
- GIS, GPS, PDA
- Extensive fracture data
- Integrate with hydrologic studies

Geologist's perspective --

We collect all this great information, how can it be used in hydrologic modeling?

Hydrologist's perspective --

We have all these great models, how can we make them work better in the most complex environments (fractured rock aquifers).

Case Studies

Hubbard Brook Experimental Forest, NH

Windham quadrangle, NH

Pinardville quadrangle, NH

West Newbury, MA

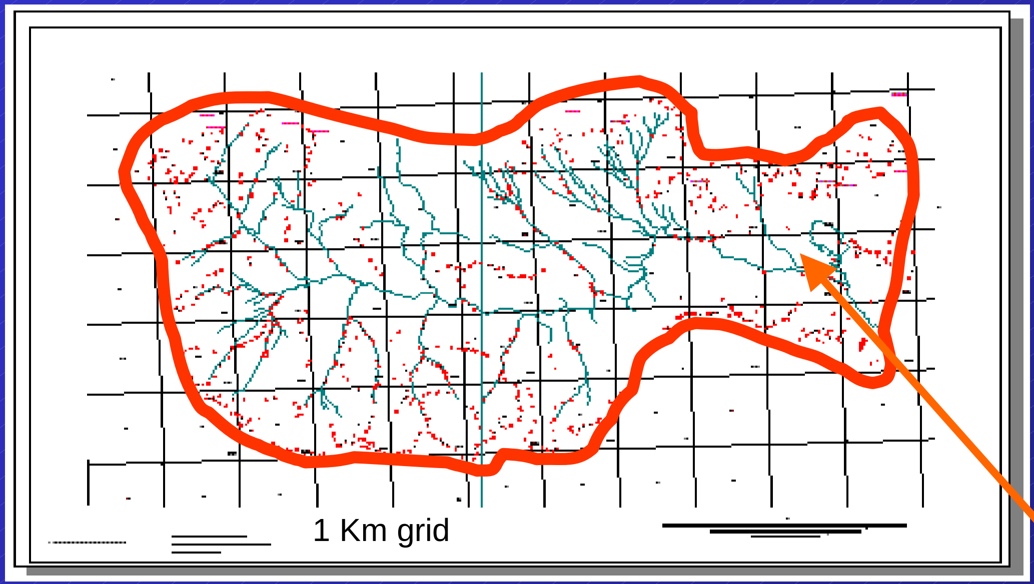
Maynard, MA

East Mahantango Creek, PA

Lawrenceville, GA

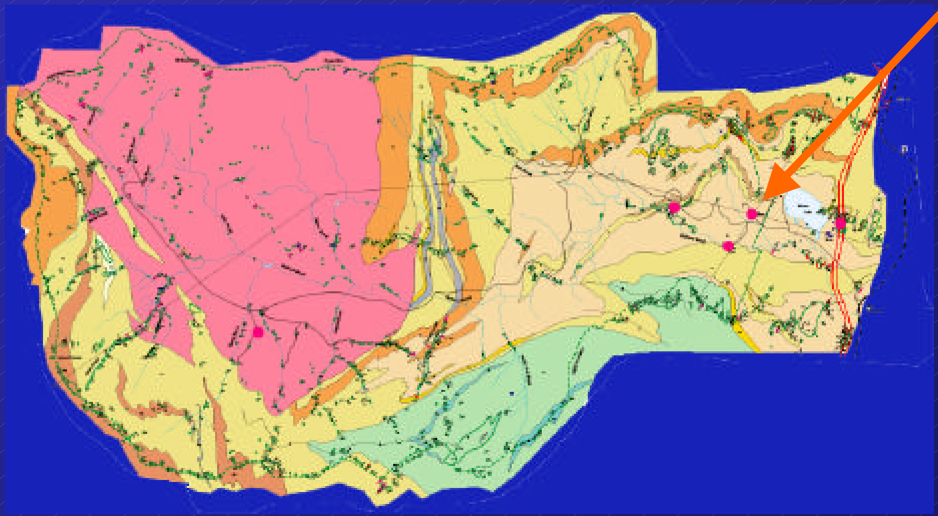
Hubbard Brook Experimental Forest, NH

What is the regional bedrock framework for Mirror Lake well fields?



Location of fracture measurements & 1 km grid

Well Fields



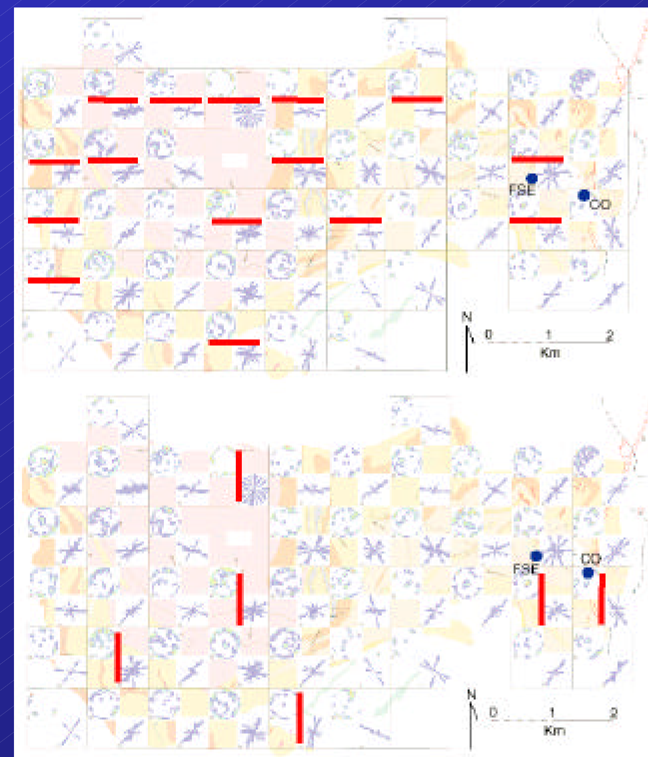
Bedrock Geology

Hubbard Brook Experimental Forest, NH

NE

NW

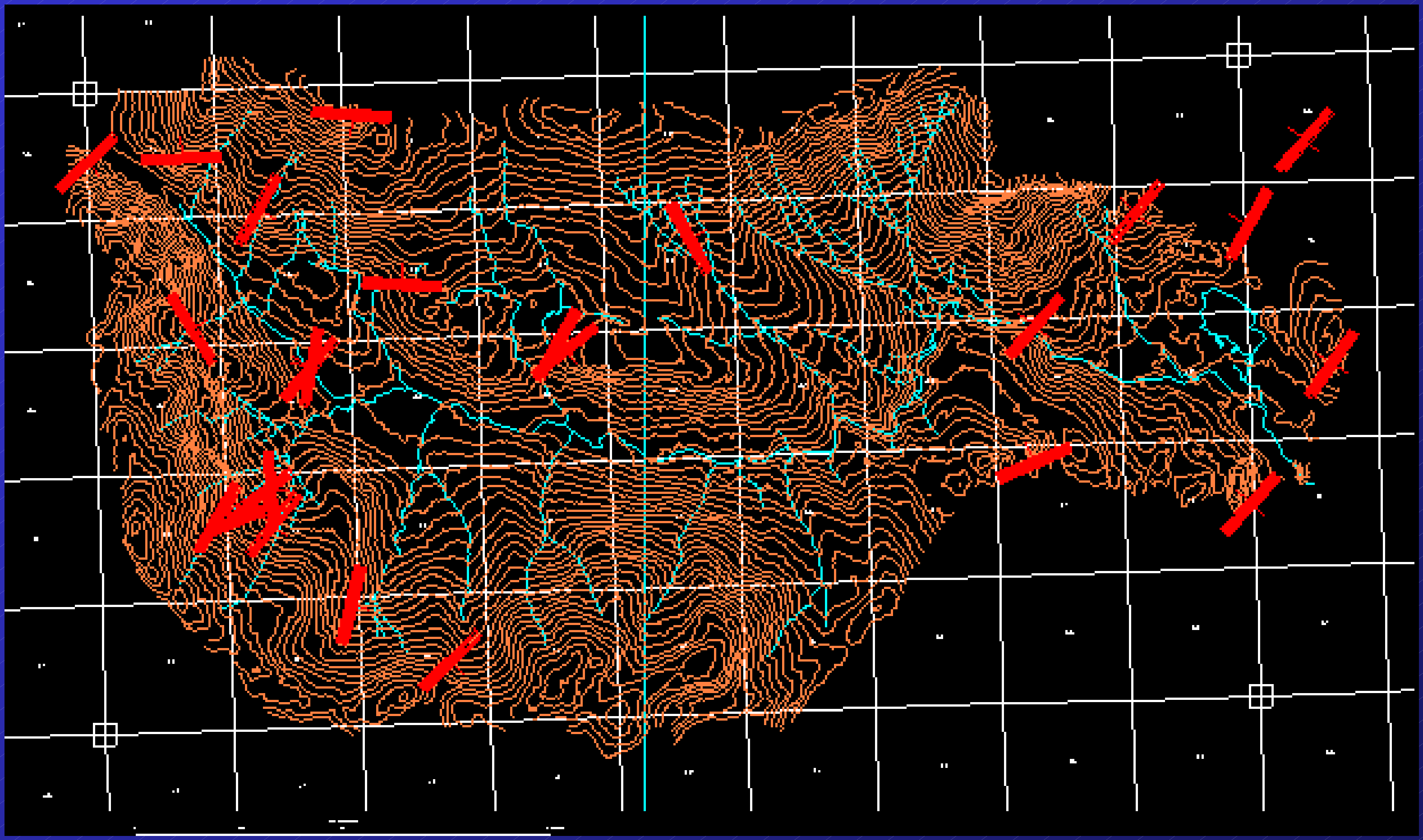
EW



NS

Principal Fracture Trends

Cretaceous diabase & lamprophyre dikes



> Principally NE-SW trends

> E-W trends in northwest

Coincident with fracture trends

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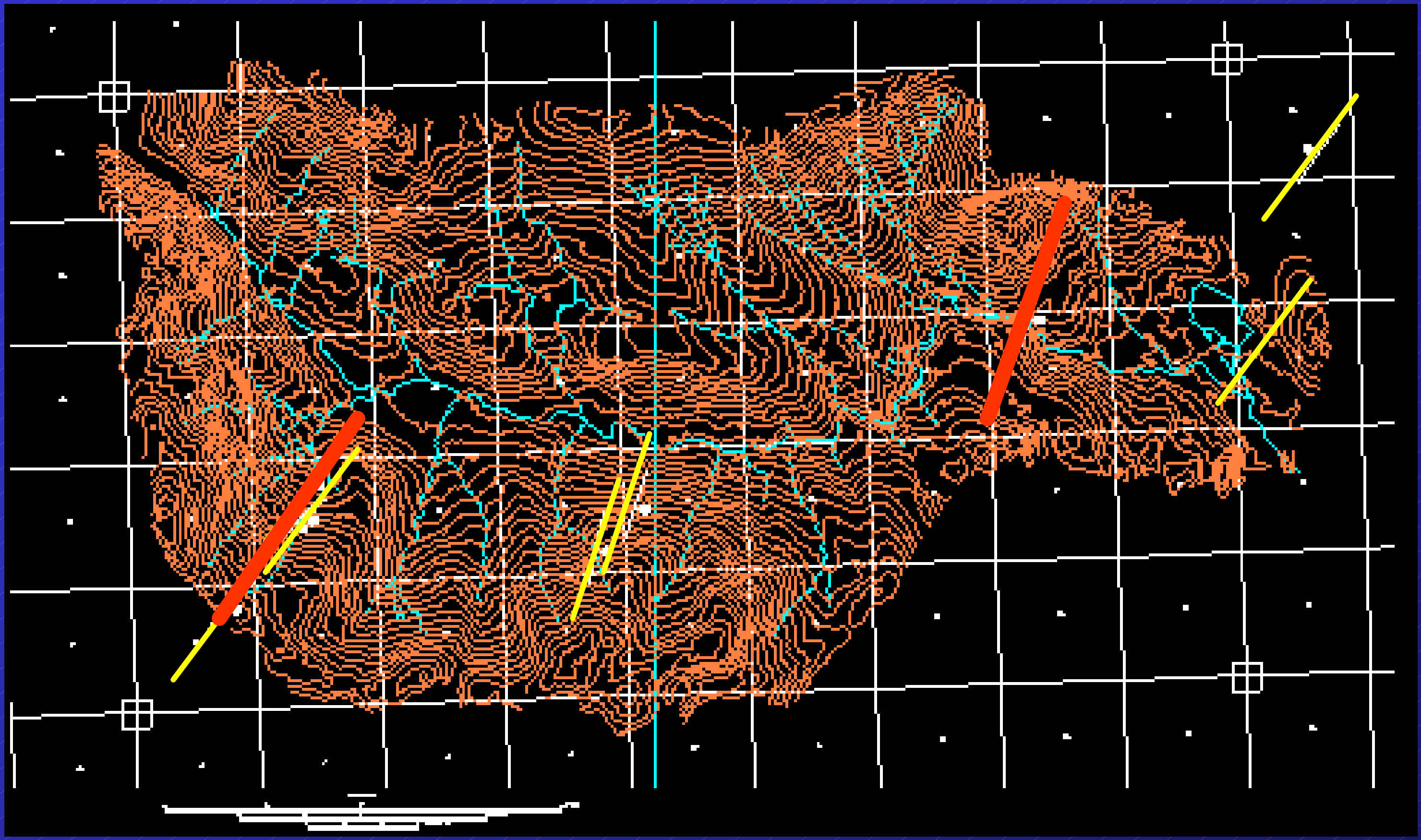
Kineo Brook The Gorge



FAULTS

> Majority trend NE-SW and are normal

> Trend is coincident with the principal fracture trend

Hubbard Brook Experimental Forest, NH

Orientation of principal fracture trend is NE

Includes joints, dikes, faults and foliation in eastern part of watershed

Agrees with principal trend in

> well fields (Johnson, 1999)

> I-93 road cut (Barton and others, 1997)

> surface geophysics at "The Gorge" (Powers and others, 1999)

Fracture orientations at well fields -- not atypical

Granite dikes in eastern part of watershed -- atypical

Granite more fractured than other rocks in wells (Johnson, 1999)

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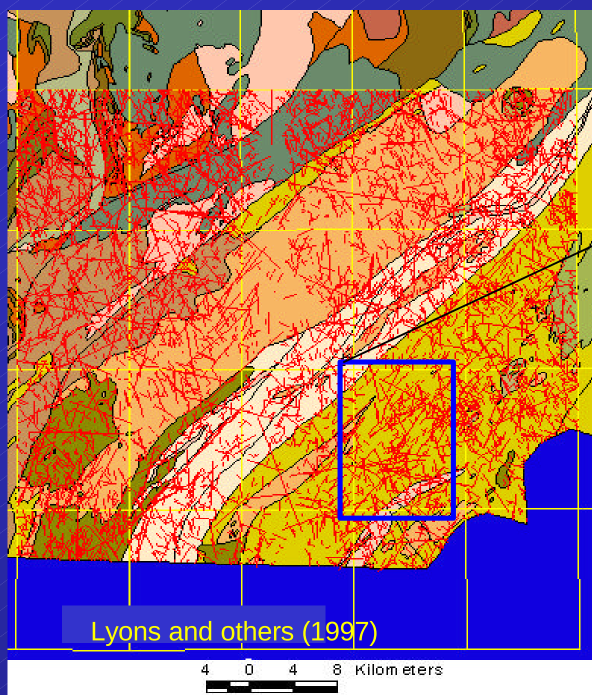
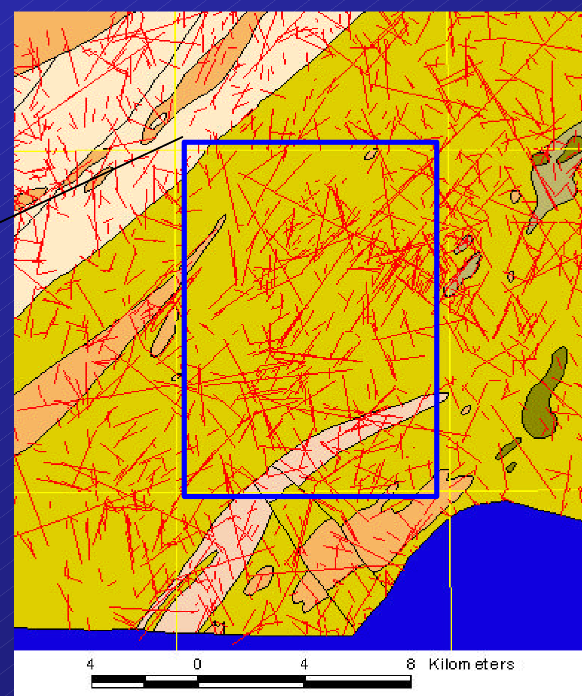
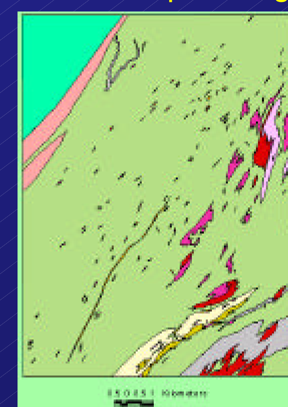
science for a changing world

Geologic Controls On Remotely Sensed Lineaments In Southeastern New Hampshire





Windham quadrangle

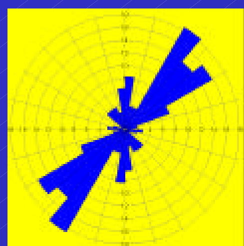


(Walsh and Clark, 1999)

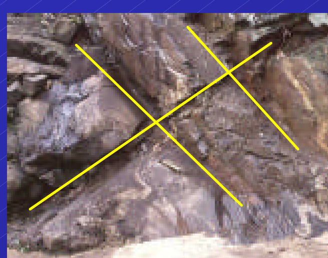
Lineament Filtering

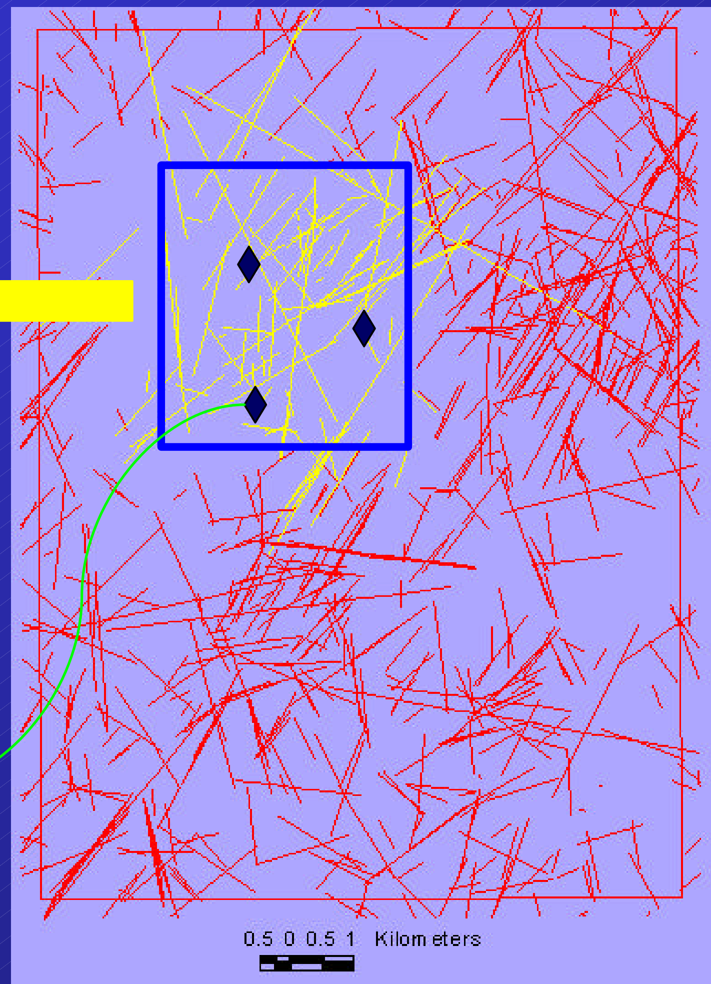
Using a Regional Approach

Sample lineaments from an area



Measure fractures from selected points in the area





Statistical correlation exists if...

fractures = lineaments

Assumes trends apply to entire region

Discrete Lineament Analysis

Does a specific lineament correlate with any geologic structures on the ground?

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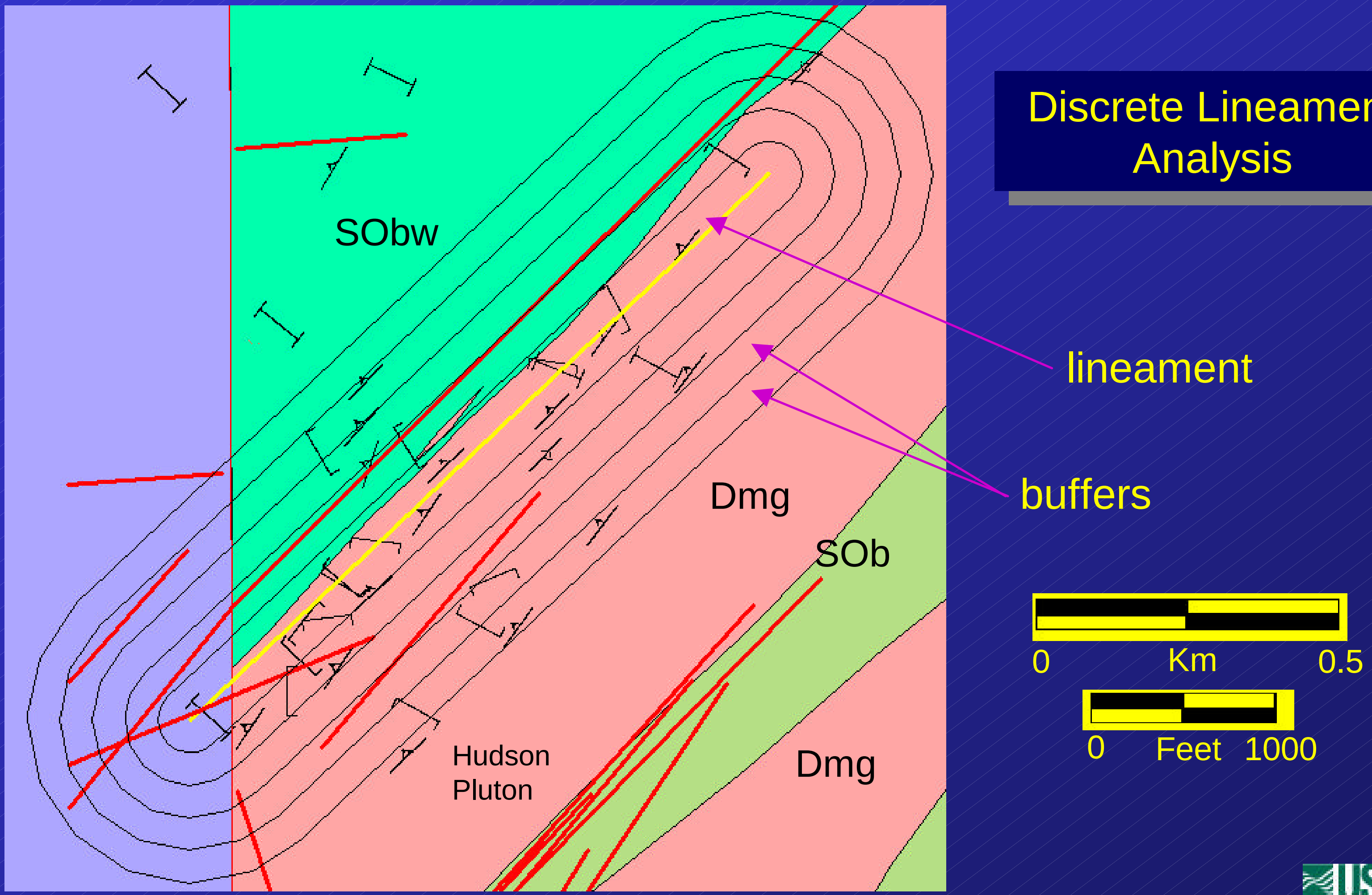
Discrete Lineament Analysis



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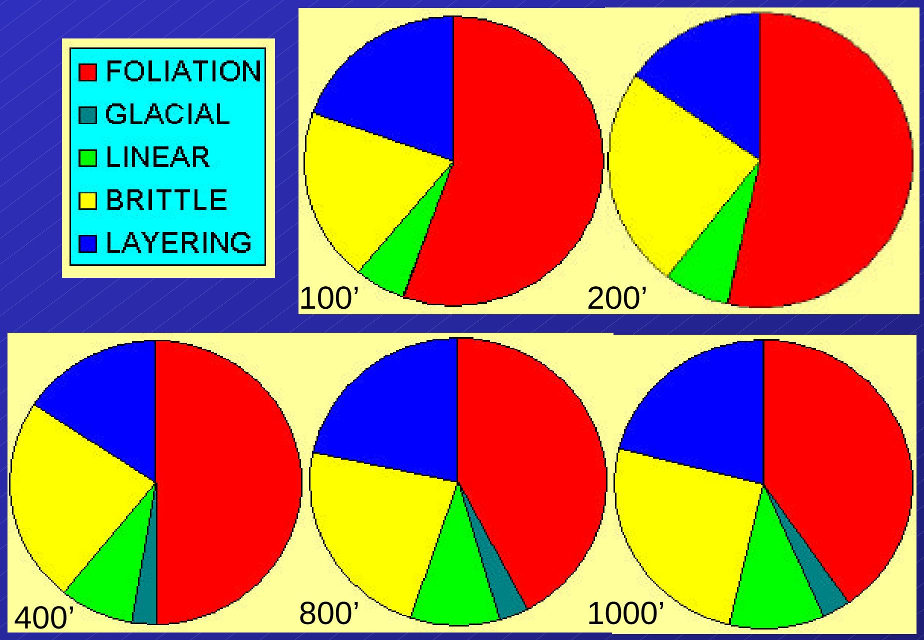
Summary of structure-correlated lineaments by buffer

	Avg.	*SD*
Foliation	48	6
Glacial	2	1
Linear	8	2
Brittle	23	2
Layering	19	3



- *Discrete Lineament Analysis*
  - Addresses spatial distribution without assuming that statistical trends apply to regions
  - Answers the single lineament correlation question
- *Demonstrates need to incorporate comprehensive structure data in lineament filtering*
- *Not all lineaments are fracture-related*

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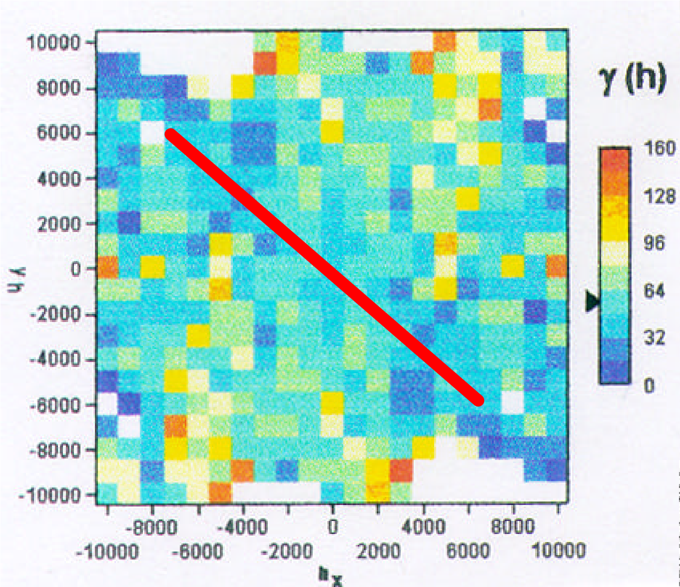
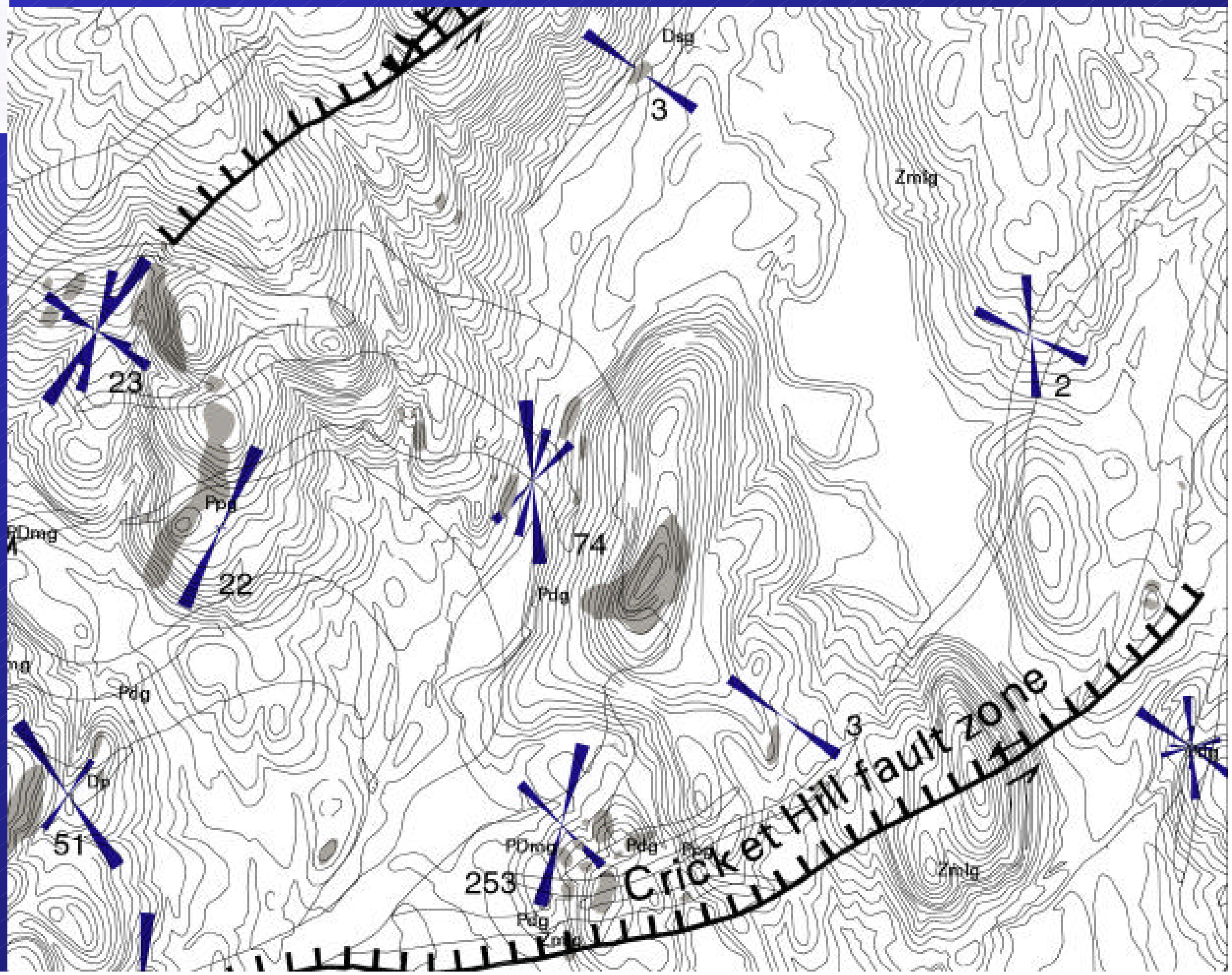


NW-trend in low variance is parallel to primary fracture trend in metasedimentary rocks of the Rangeley Formation

Fracture Frequency-Azimuth Plots



Private-Domestic Well Variogram

Drew and others (1999)

Pinardville Quadrangle, NH

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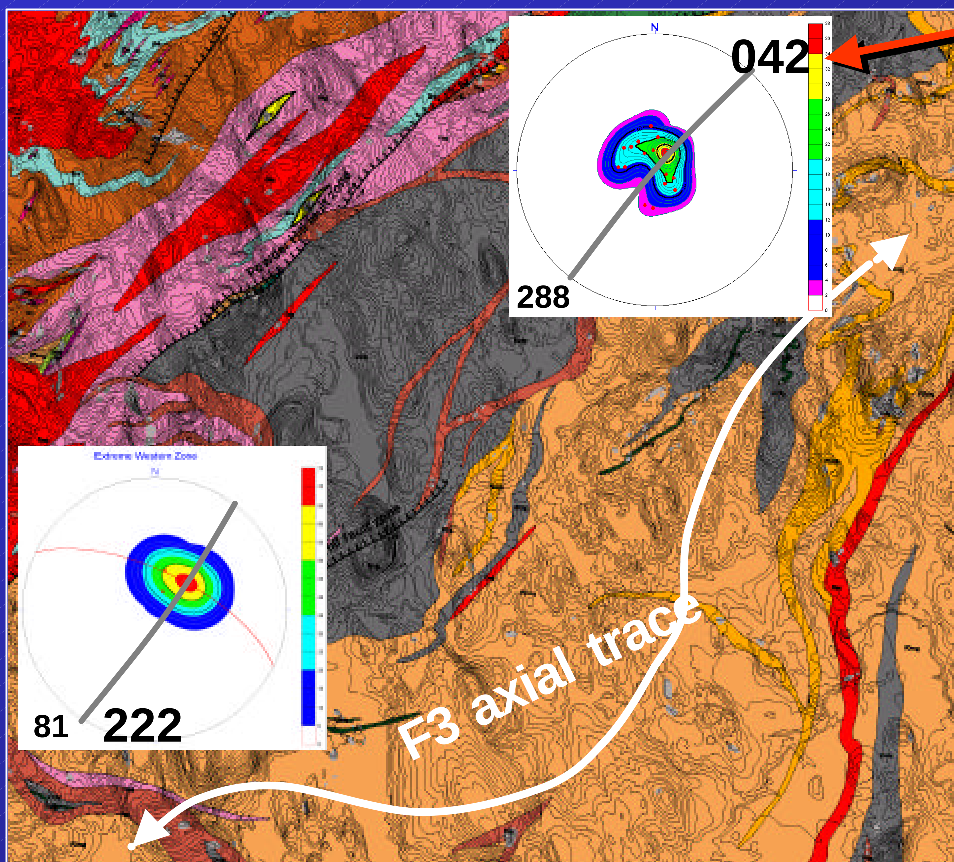
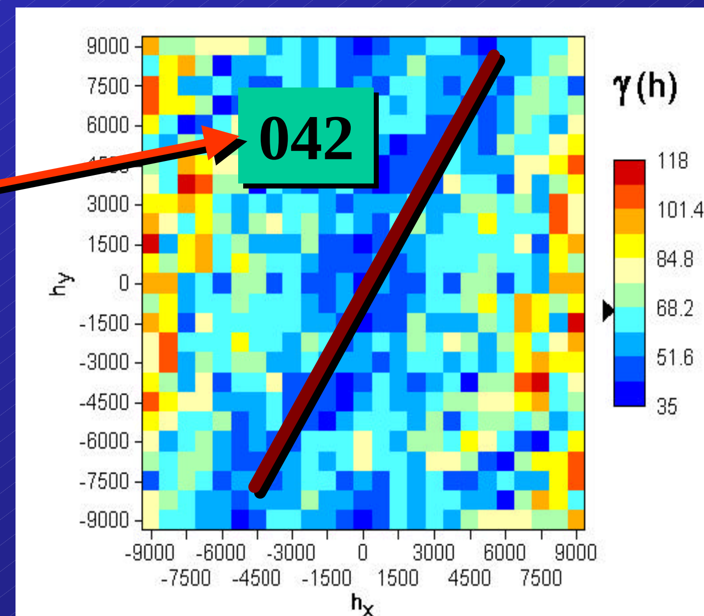
Correlation between Fractures and Well Data

Sheeting fractures & folded cleavage in Massabesic Gneiss define an anticlinal axis that trends 042





Same *trend is in the well yield variogram*

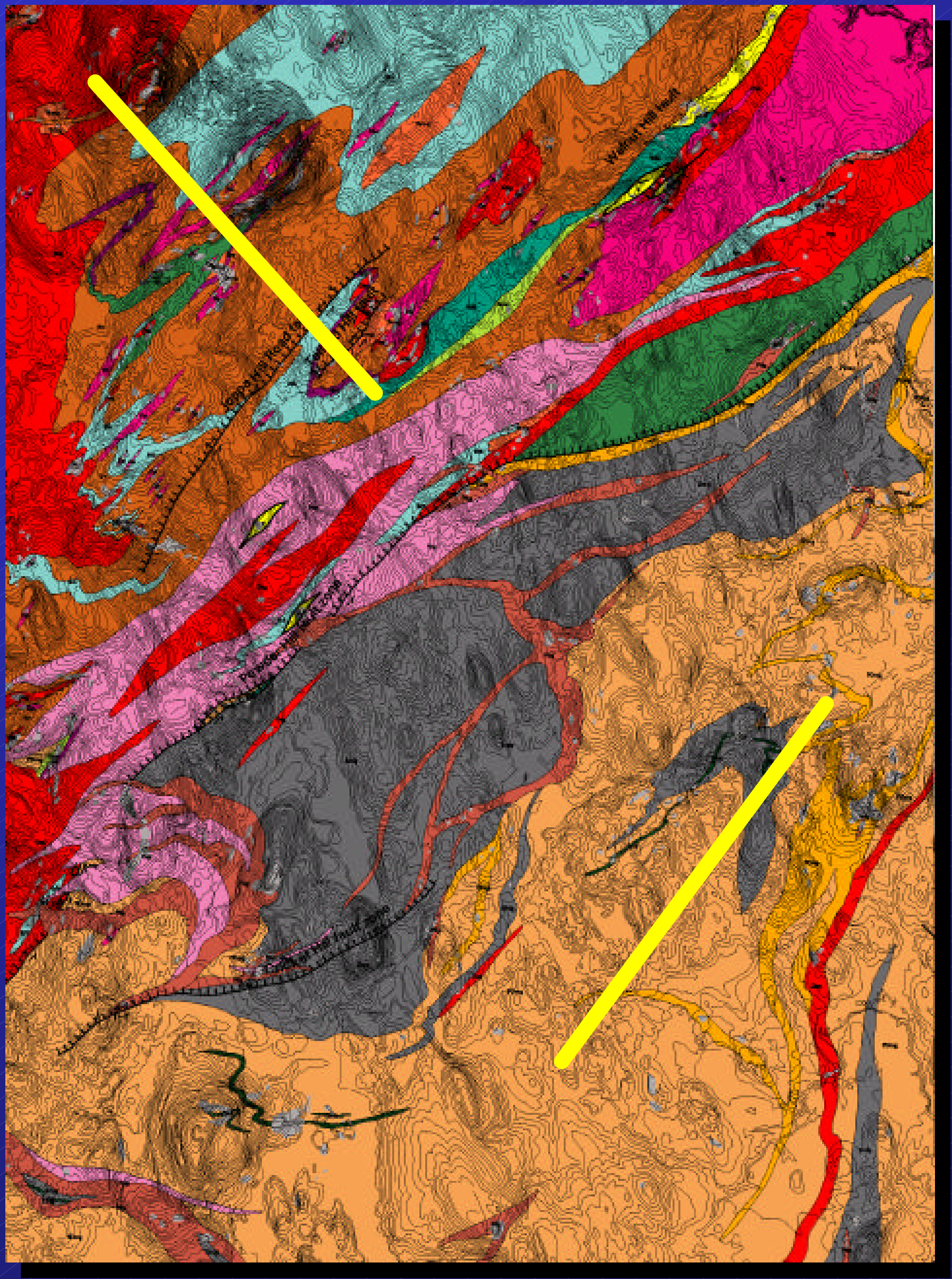
Drew and others (1999)

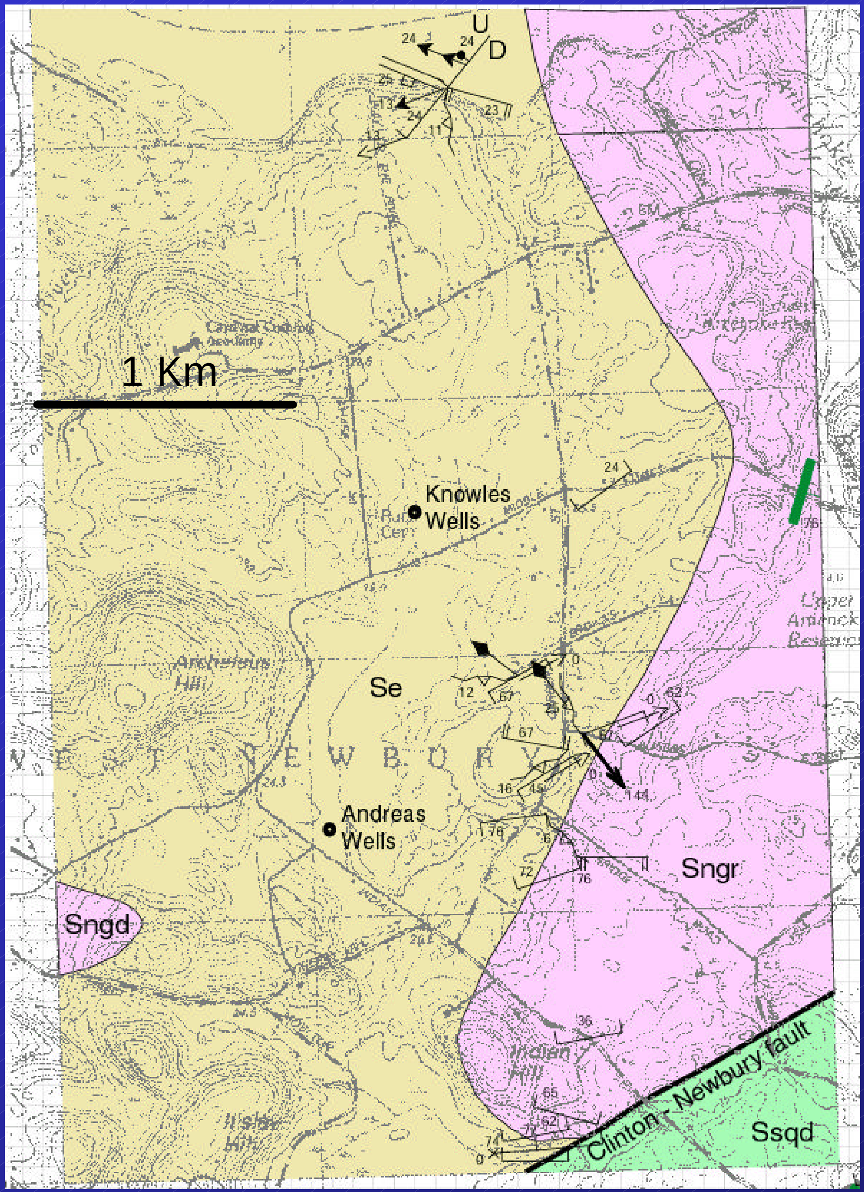
Geologic Map
of the
Pinardville 7½ Minute Quadrangle
Southwestern NH
By
Armstrong & Burton
(in press)

1:24,000 Scale

Variography indicates a directional link between well yield and geologic structure by rock type

Drew and others (1999)

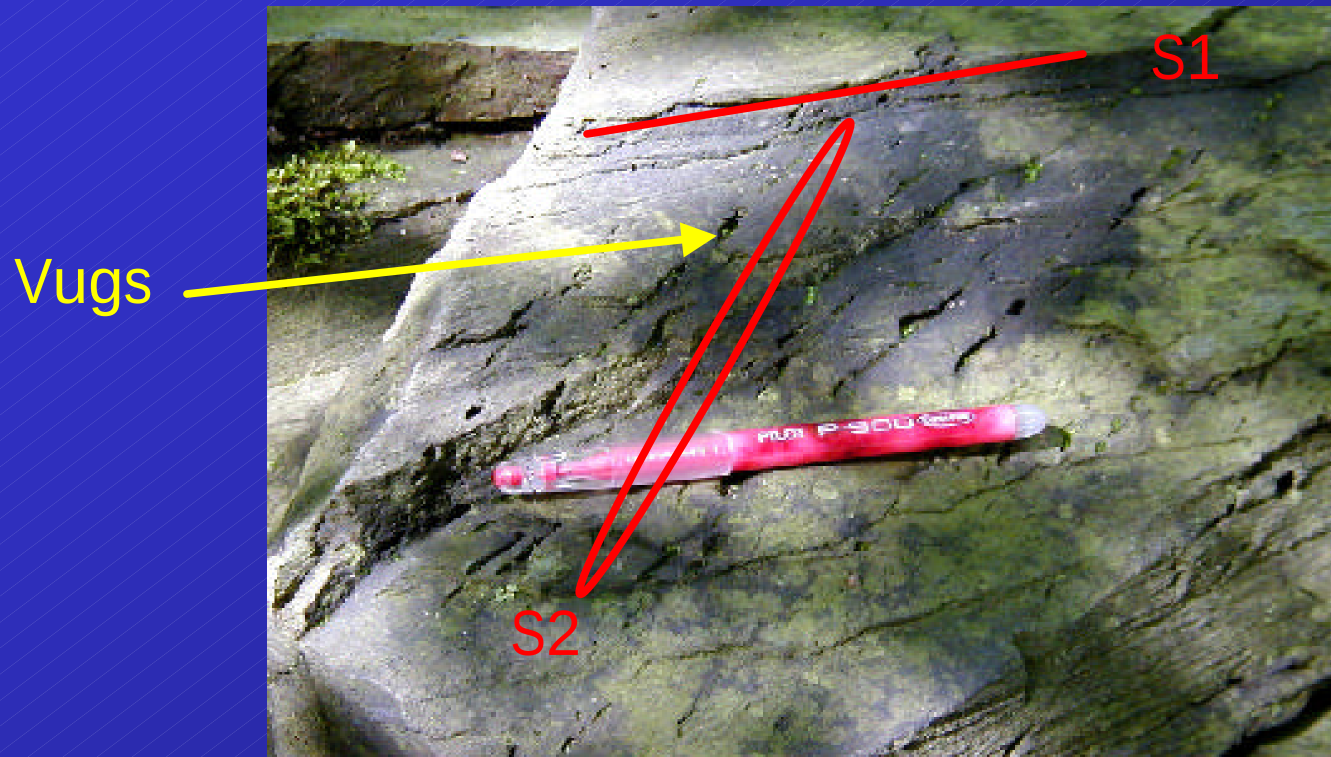




West Newbury, MA

ZOCs for high-yield fractured bedrock aquifers

100-200 gpm

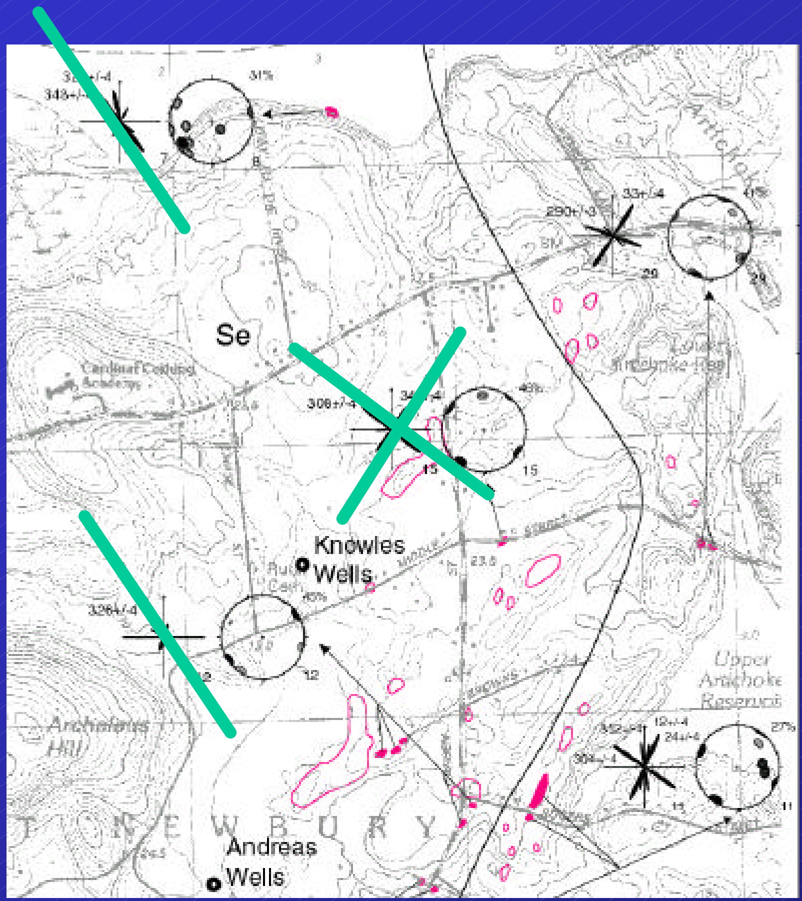


Solution cavities in the Eliot Formation parallel to:

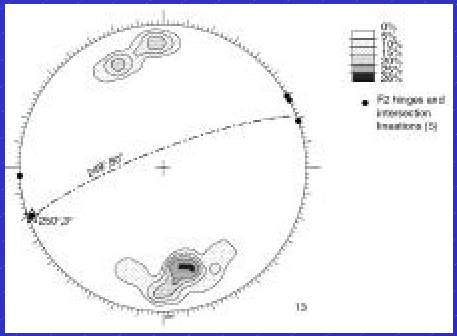
S2 cleavage

S1 layer parallel foliation

Joints

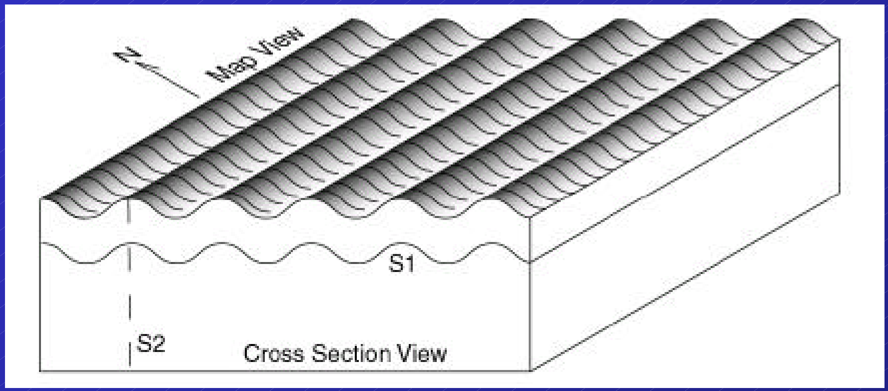


Fractures in the Eliot Formation dominated by NW trends, but some NE trends near Knowles Well Field

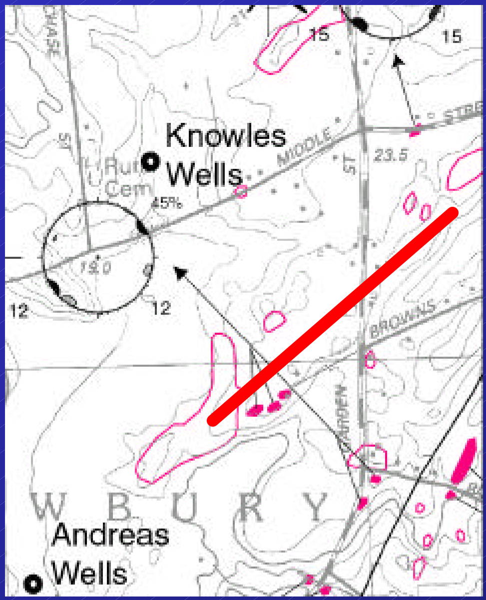


Steeply dipping

S2 cleavage & F2 folds



Combined with sub-horizontal S1



Control bedrock topography and produce

NE trending ridges and valleys

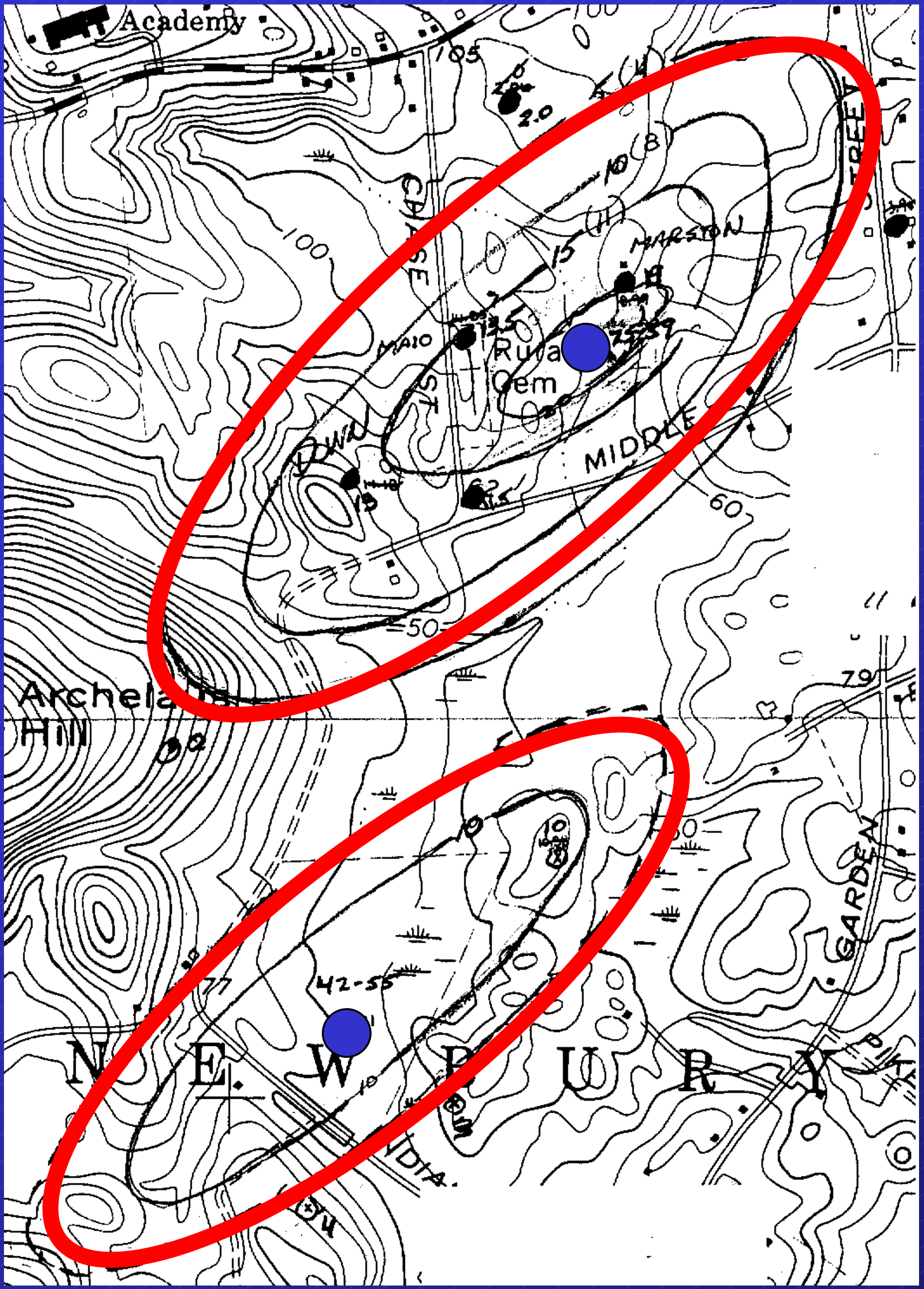
Directional anisotropy in the bedrock is a function of:

Corrugated S1

Bedrock topography

S2 cleavage with vugs

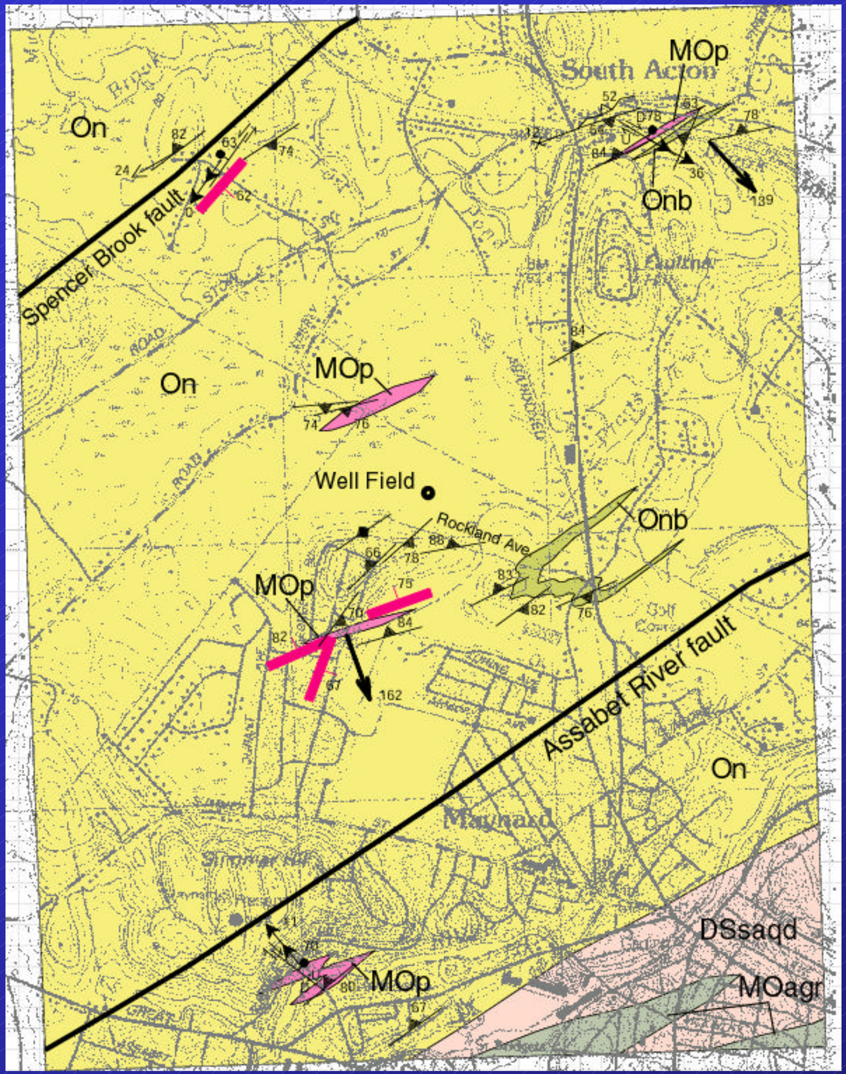
Steep fractures to NE & NW



Elliptical drawdown oriented NE during 11 day pump test

Preliminary results from Lyford and others

Drawdown agrees with directional anisotropy in bedrock



Maynard, MA

ZOCs for high-yield fractured bedrock aquifers

1000 gpm

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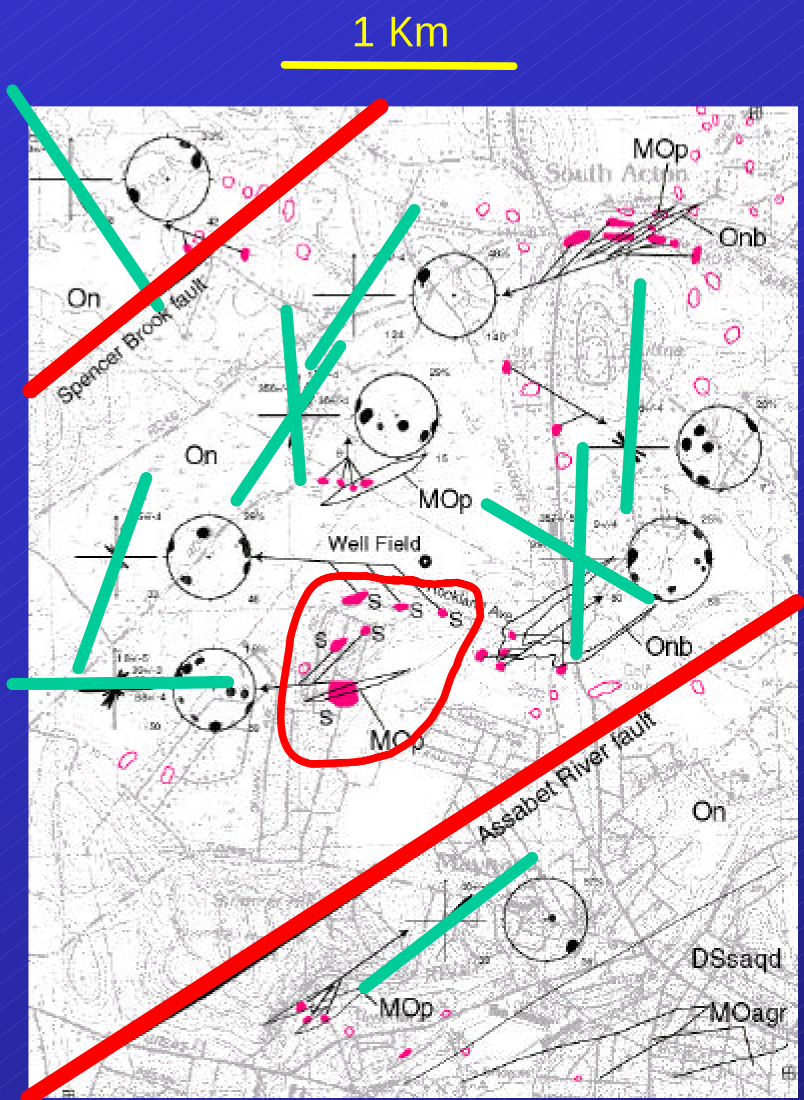
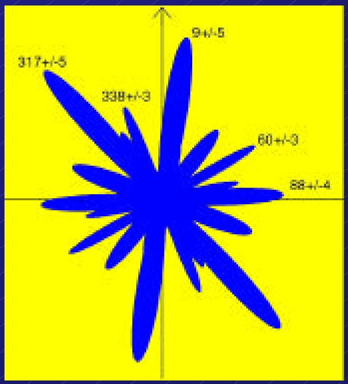
Fractures in the Nashoba Formation have heterogeneous trends near the well field



Regional Faults



Associated sulfide mineralization

Maynard, MA

Highly fractured

Fractures are related to sulfide mineralization and possibly regional faults

Heterogeneous directional anisotropoy

Extent of fracturing is probably the cause of high yield

How do we use these factors for establishing ZOCs and for future prospecting?

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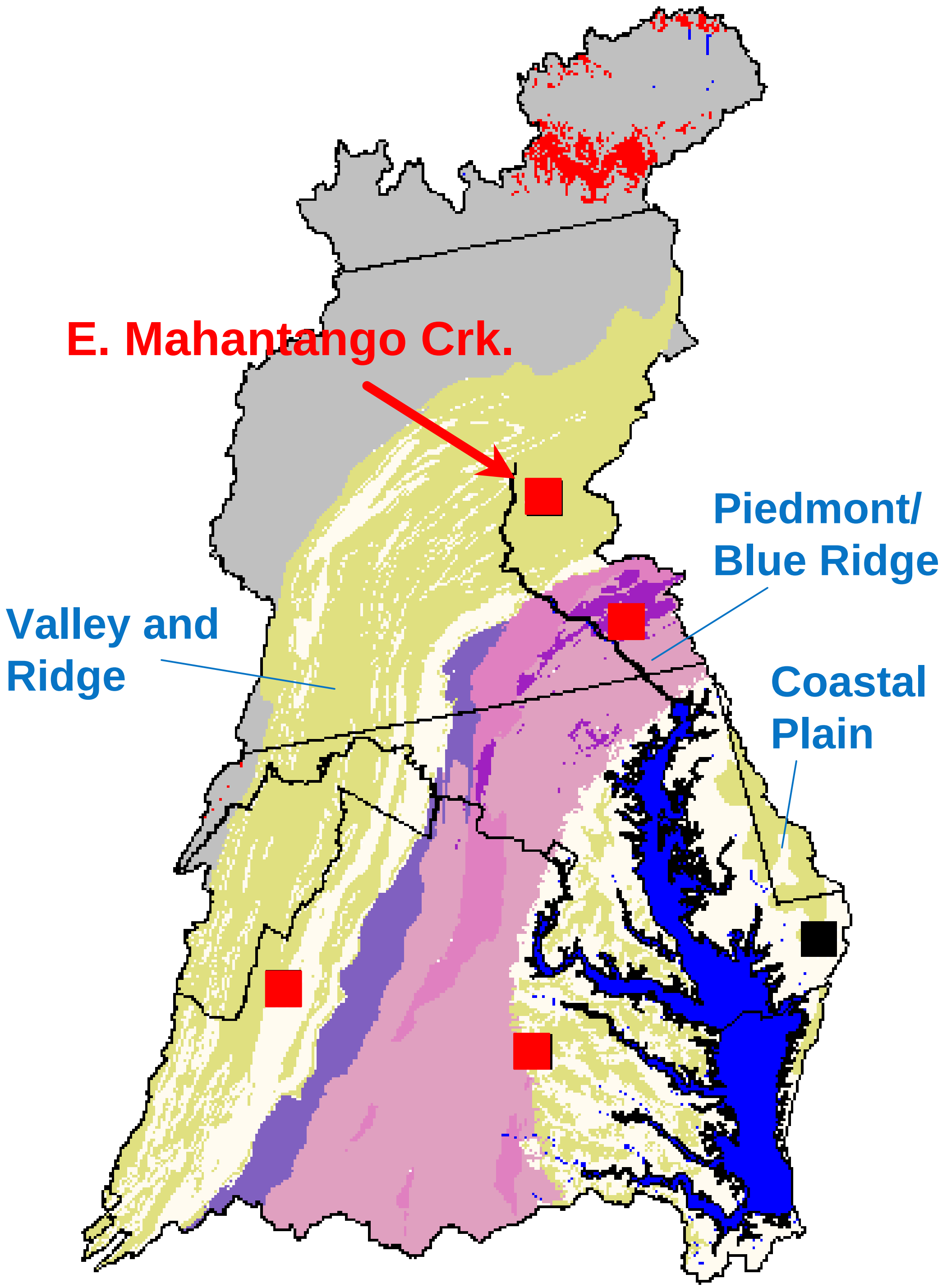
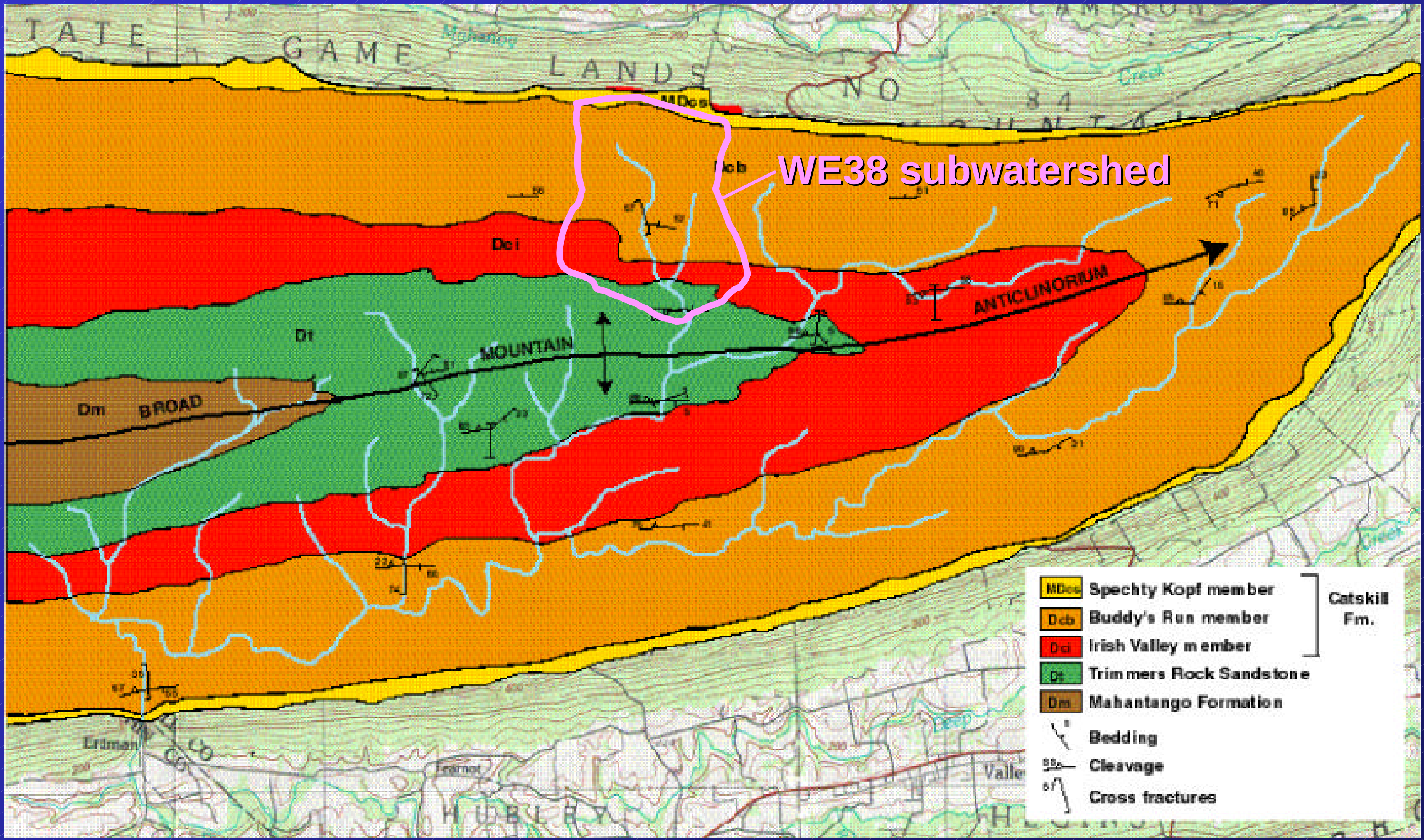
USGS Chesapeake Bay watershed nutrient study

- Model influx of nitrogen into Bay
- Four “targeted watersheds” in high-nitrate-source areas underlain by fractured bedrock
- What is effect of bedrock geology on base flow and ground-water travel times?



East Mahantango Creek watershed--developed on anticline in Devonian-Mississippian sandstones and shales



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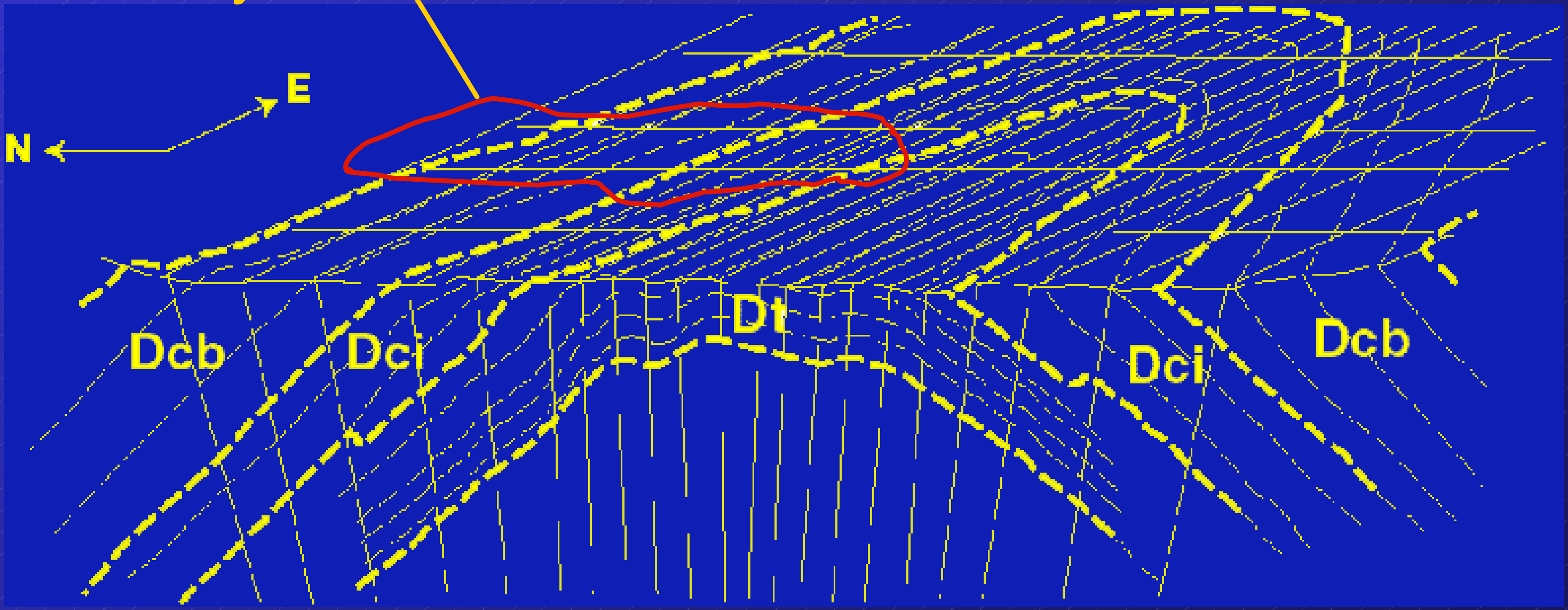
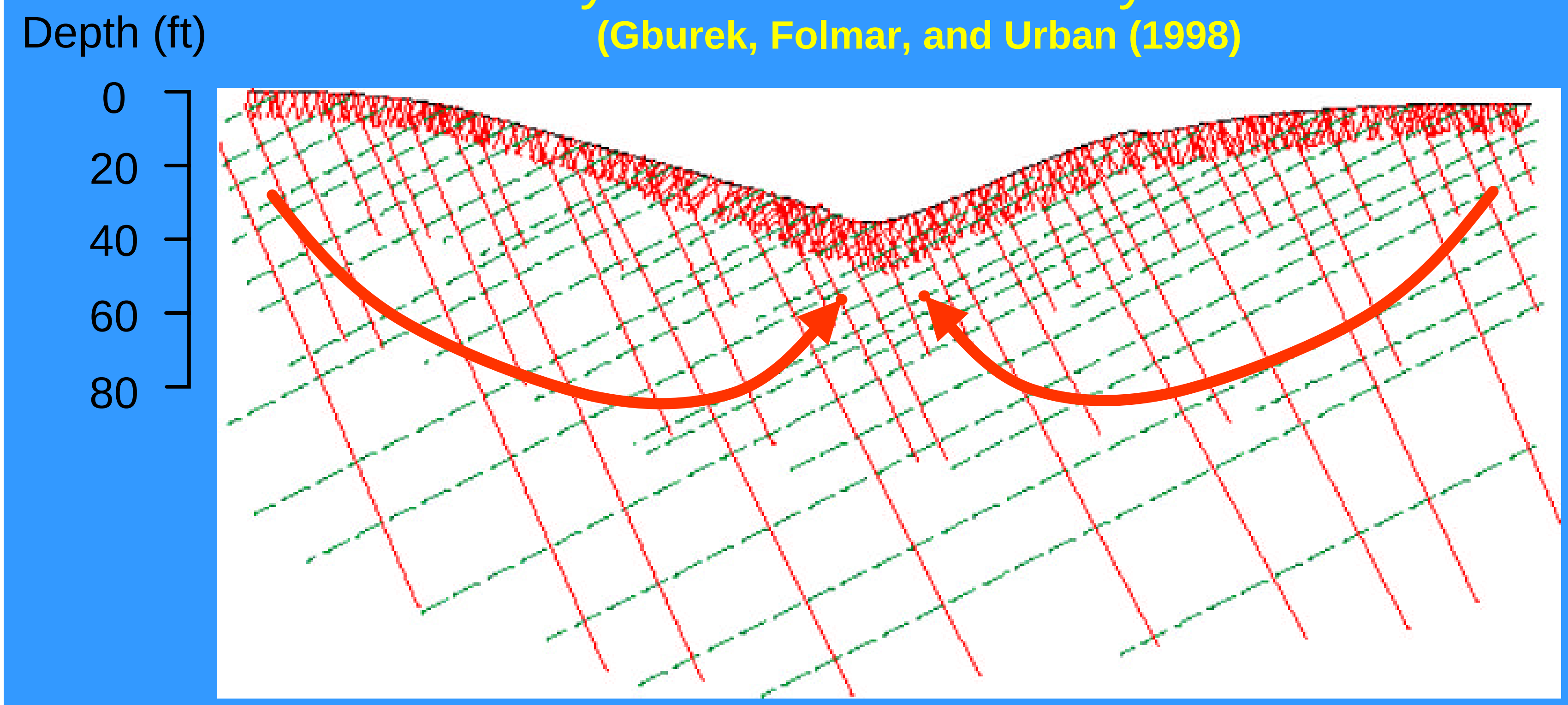
East Mahantango Creek watershed bedrock fracture framework

WE38 subwatershed:
ground water dating
study area



Layered fracture density model

(Gburek, Folmar, and Urban (1998)



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East Piezometer Transect

--Preferred CFC-12 ages NE of stream are older...

..than those underneath and SW of stream

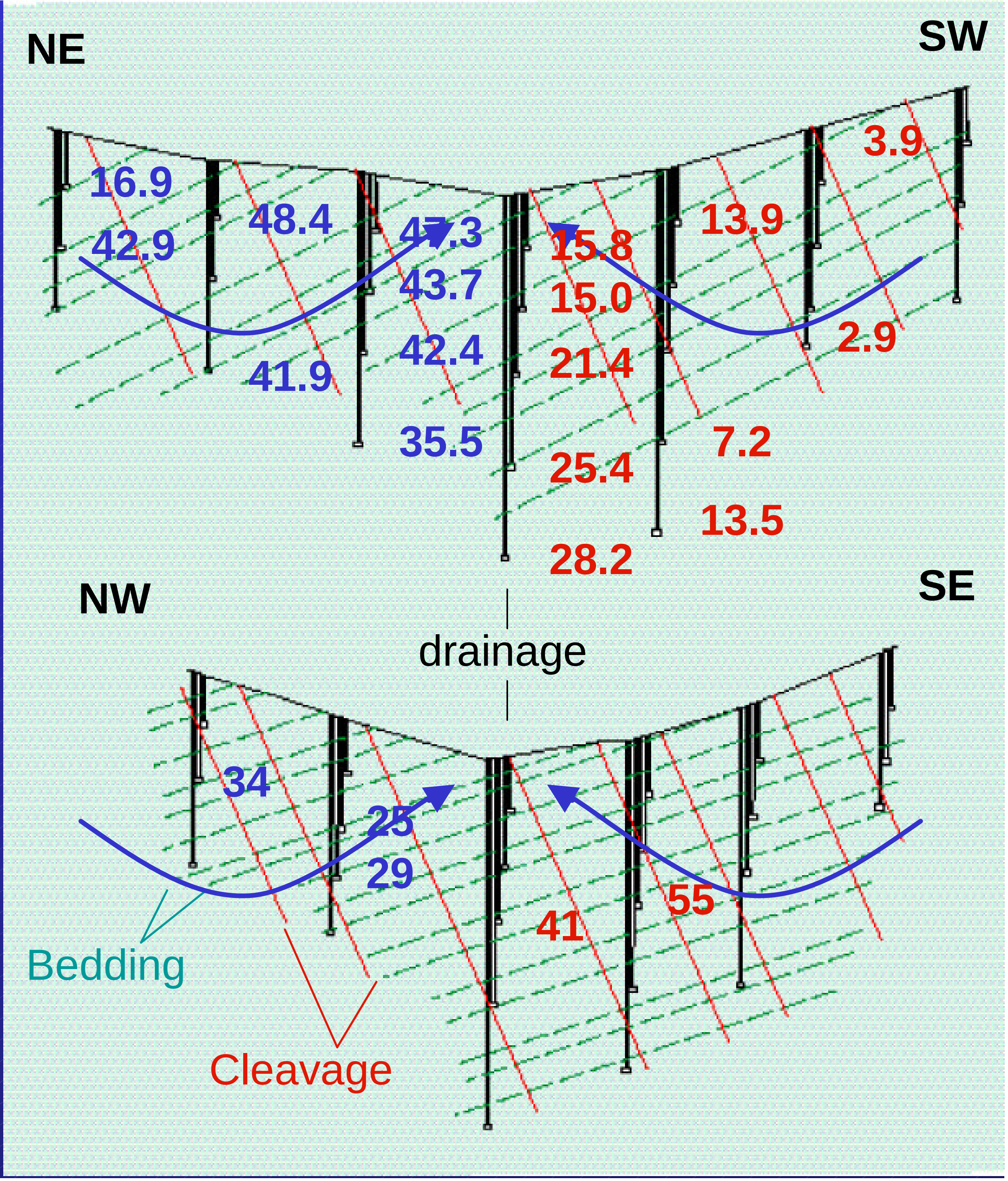
..although these ages are really mixed ages!

West Piezometer Transect

--Ages are too mixed even to assign numbers

--but older waters predominate to NW...

…and younger to SE



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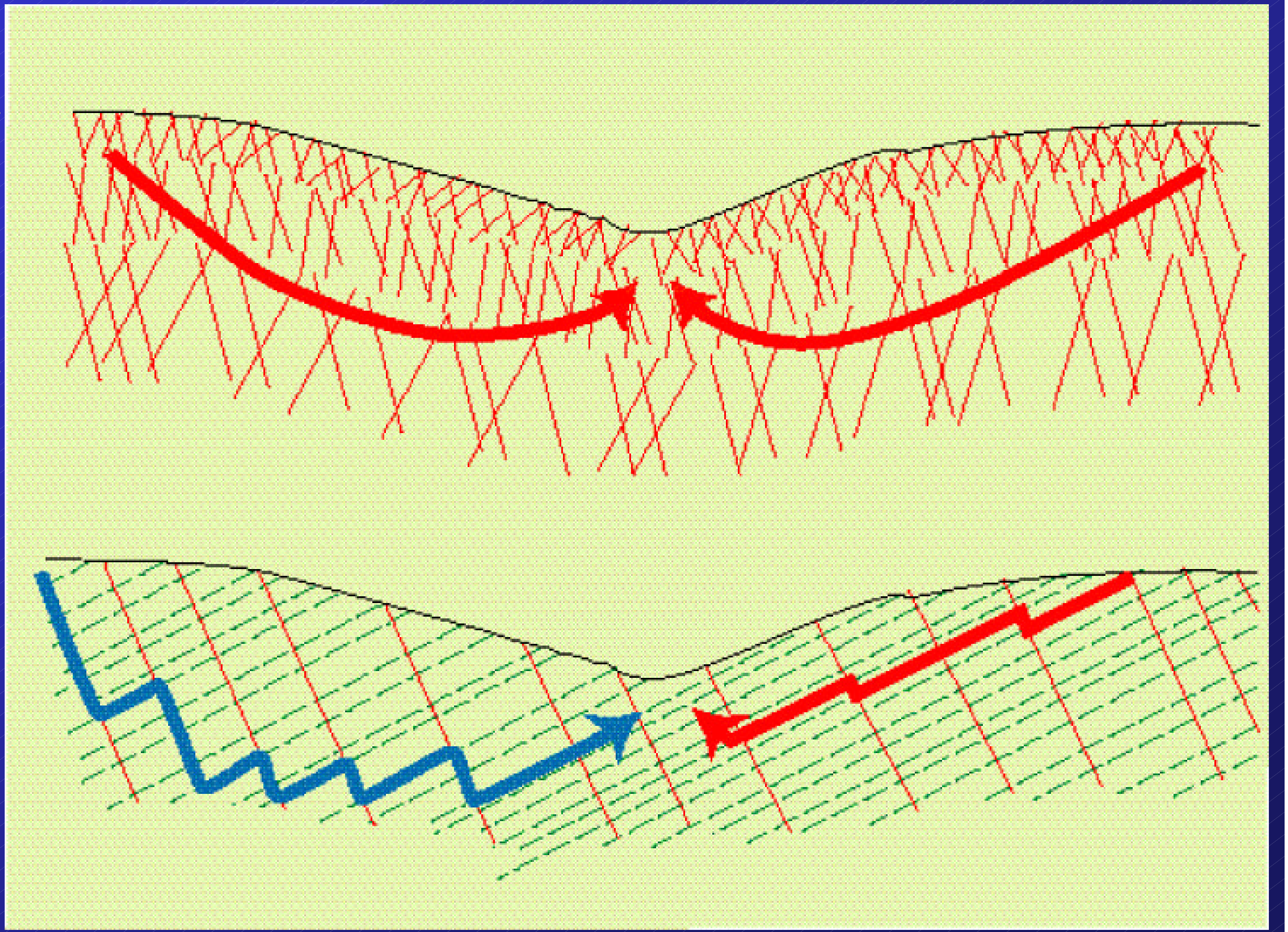
Bedding-plane anisotropy explains disparity in ground-water ages, travel times

Layered-density, isotropic fracture model
Young, equal GW ages at discharge

Bedding-plane fracture model
Predominantly young water downdip to discharge; old water updip to discharge



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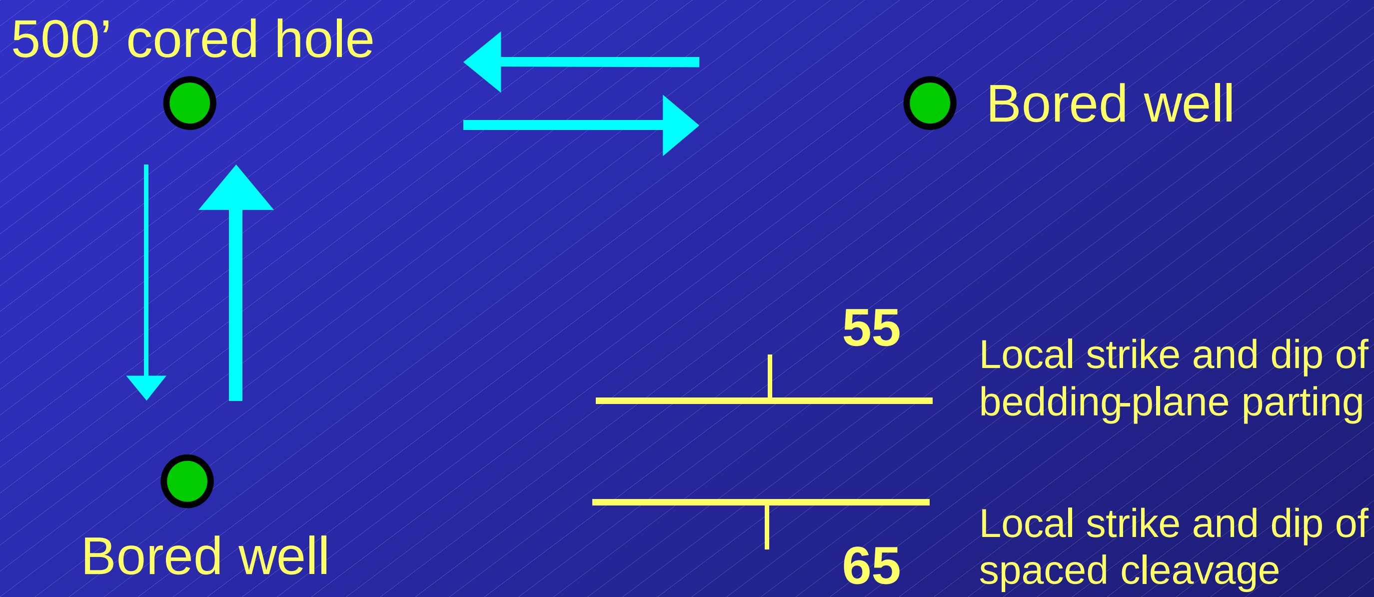
Future Work



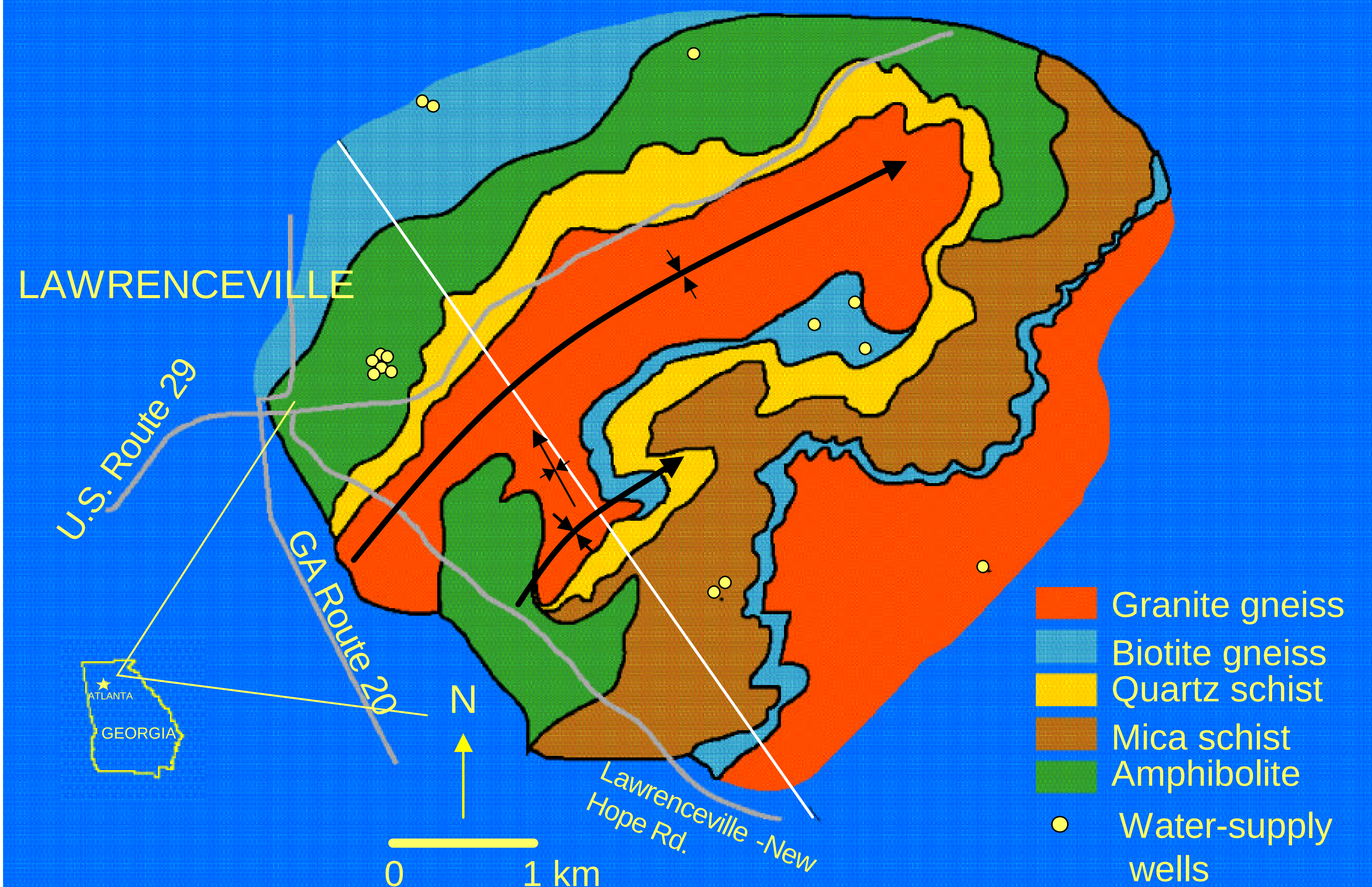
Cross-hole pump tests at Mahantango will test effect of anisotropic fracture geometry on GW flow

East Mahantango Creek

- Fracture anisotropy can influence ground-water travel times

- Regional fracture geometry can have influence on streamflow behavior--with implications for large-scale modeling

Lawrenceville, GA



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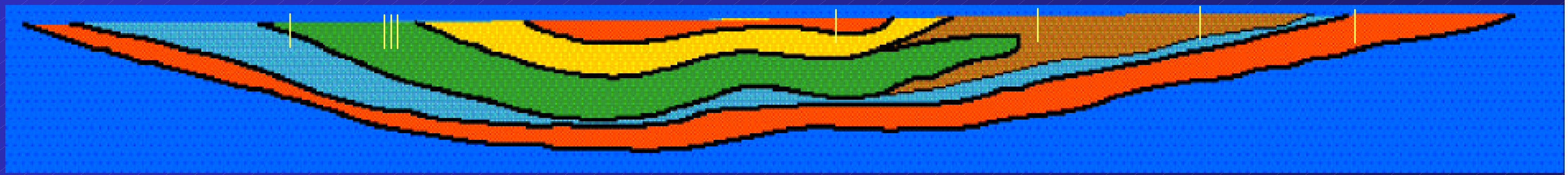
The Lawrenceville area consists of gently-dipping thrust sheets in a broad synform.

The lithologies in these sheets have greatly differing ground-water yields

Ground water yields in these rocks are controlled primarily by weathered-out voids parallel to foliation, not steeply-dipping brittle fractures--hence the strong lithologic control

NW SE



CONCLUSIONS

A new generation of geologic maps provide previously unavailable insight into the framework of fractured rock aquifers

New maps with new technology (GIS, GPS, PDA)

Enables statistical analysis

Identifies and provides…

- Regional framework
- Directional anisotropy
- Structural control on flow-paths
- Lithologic control
- Control on remotely sensed data